CHAPTER 4

ELASTIC MODULI OF PAVEMENT MATERIALS

4-1. Climatic Factors.

In the design system, two climatic factors, temperature and moisture, are considered to influence the structural behavior of the pavement. Temperature influences the stiffness and fatigue of bituminous material and is the major factor in frost penetration. Moisture conditions influence the stiffness and strength of the base course, subbase course, and subgrade. Temperature does not influence the stiffness and fatigue of the PCC, but temperature differential in the concrete can cause the slab to warp and break easily. In concrete pavements, moisture differential can also cause the slab to warp but the effect is relatively minor.

a. Design pavement temperature Pavement is generally designed for two different failure modes. One is for the shear failure in the subgrade and the other is for the fatigue cracking in the surface layers. The design procedure requires the determination of one design pavement temperature for consideration of vertical compressive strain at the top of the subgrade and horizontal tensile strain at the bottom of cement- or lime-stabilized layers and a different design pavement temperature for consideration of the fatigue damage of the bituminous concrete surface. In either case, a design air temperature is used to determine (figure 4-1) the design (mean) pavement temperature. Temperature data for computing the design air temperatures are available from the National Oceanic and Atmospheric Administration (NOAA) "Local Climatological Data Annual Summary with Comparative Data." With respect to subgrade strain and fatigue of cement- and lime-stabilized base or subbase courses, the design air temperature is the average of two temperatures: (1) the average daily mean temperature and (2) the average daily maximum temperature during the traffic period. The traffic period is normally 1 month. For consideration of the fatigue damage of bituminous materials, the design air temperature is the average daily mean temperature. Thus, for each traffic period, two design air temperatures are determined. For design purposes, it is best to use the long-term averages such as the 30-year averages given in the annual summary. As an example, the determination of the design pavement temperatures for 10-inch bituminous pavement can be demonstrated by considering the climatological data for Jackson, Mississippi as tabulated below. For the month of August, the average daily mean temperature is 81.5 degrees F., and the average daily maximum is 92.5 degrees F.; therefore, the design air temperature for consideration of the subgrade strain is 87 degrees F., and the design pavement temperature determined from figure 4-1 would be approximately 100 degrees F. For consideration of bituminous fatigue, the design air temperature for August in Jackson, Mississippi is 81.5 degrees F., resulting in a design pavement temperature of approximately 92 degrees F. (from fig 4-1). These design pavement temperatures are determined for each of the traffic periods.

	Temperature, degrees F.	
Month	Average Daily Maximum	Average Daily Mean
January	58.4	47.1
February	61.7	49.8
March	68.7	56.1
April	78.2	65.7
May	85.0	72.7
June	91.0	79.4
July	92.7	81.7
August	92.5	81.5
September	88.0	76.0
October	80.1	65.8
November	68.5	55.3
December	60.5	48.9

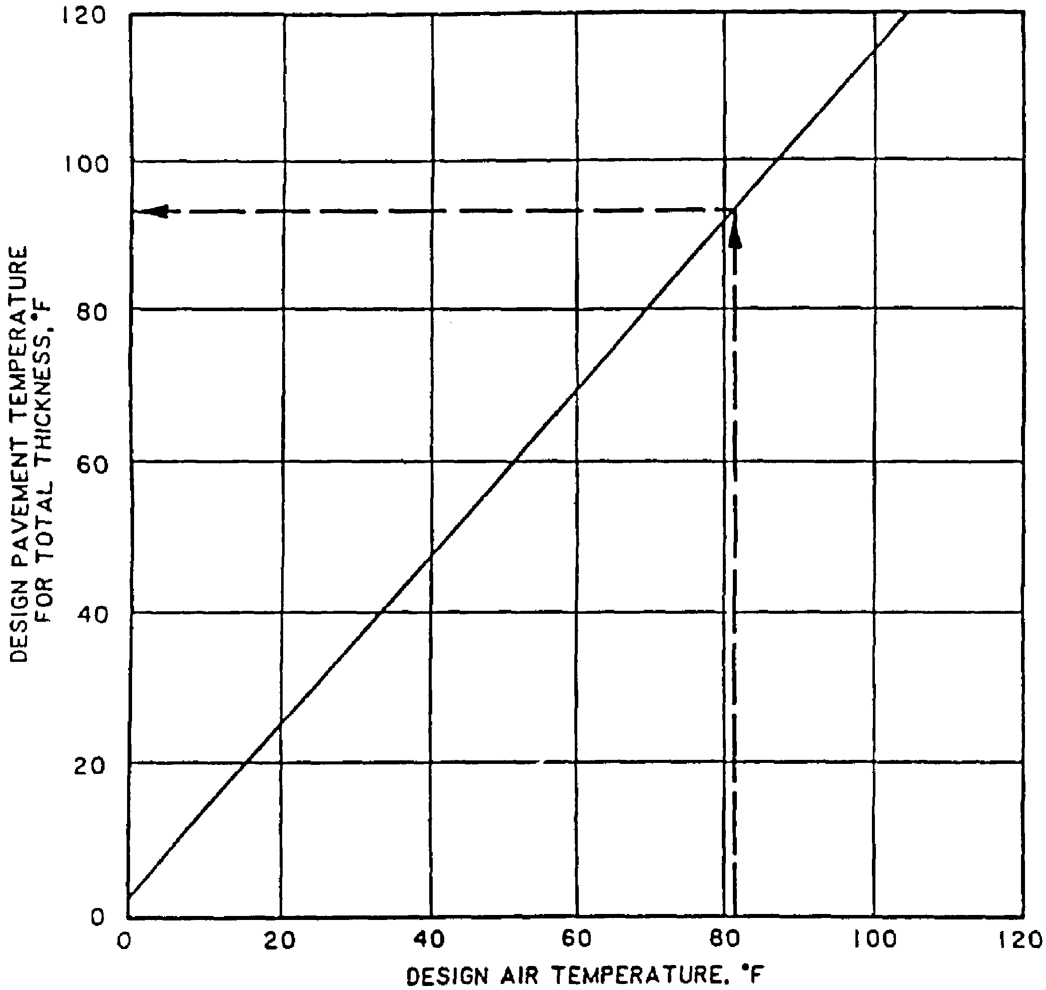

Figure 4-1. Relationship Between Design (Mean) Pavement Temperature and Design Air Temperature.

b. Thaw periods. The effects of temperature on subgrade materials are considered only with regard to frost penetration. The basic requirements for frost protection are given in TM 5-822-5/AFM 88-7, Chap. 3.

c. Subgrade moisture content for material characterization. Pavement design is usually predicated on a subgrade which is assumed to be near-saturation. The design may be based on subgrade with lower moisture content if available field measurements indicate that the subgrade will not reach saturation. These measurements must reflect the period of the year when the water table is at its highest level, and such designs must be approached with caution.

4-2. Material characterization.

Characterization of the pavement materials requires the quantification of the material stiffness as defined by the resilient modulus of elasticity and Poisson's ratio and, for selected pavement components, a fatigue strength as defined by a failure criterion. The use of layered elastic design procedures does not negate the material requirements set forth in TM 5-822-5/AFM 88-7, Chap. 3.

a. Modulus of elasticity.

(1) *Bituminous mixtures.* The term "bituminous mixtures" refers to a compacted mixture of bitumen and aggregate designed in accordance with standard practice. The modulus for these materials is determined by use of the repetitive triaxial tests. The procedure for preparation of the sample is given in TM-5-825-2-1/AFM 88-6, Chap. 2, Section A with the procedure for the conduct of the repetitive triaxial test given in chapter 9 of the same manual.

(a) The stiffness of the bituminous mixtures will be greatly affected by both the rate of loading and temperature. For roads and streets design, a loading rate of 2 to 4 hertz is recommended. Specimens should be tested at temperatures of 40, 70 and 100 degrees F. so that a modulus-temperature relationship can be

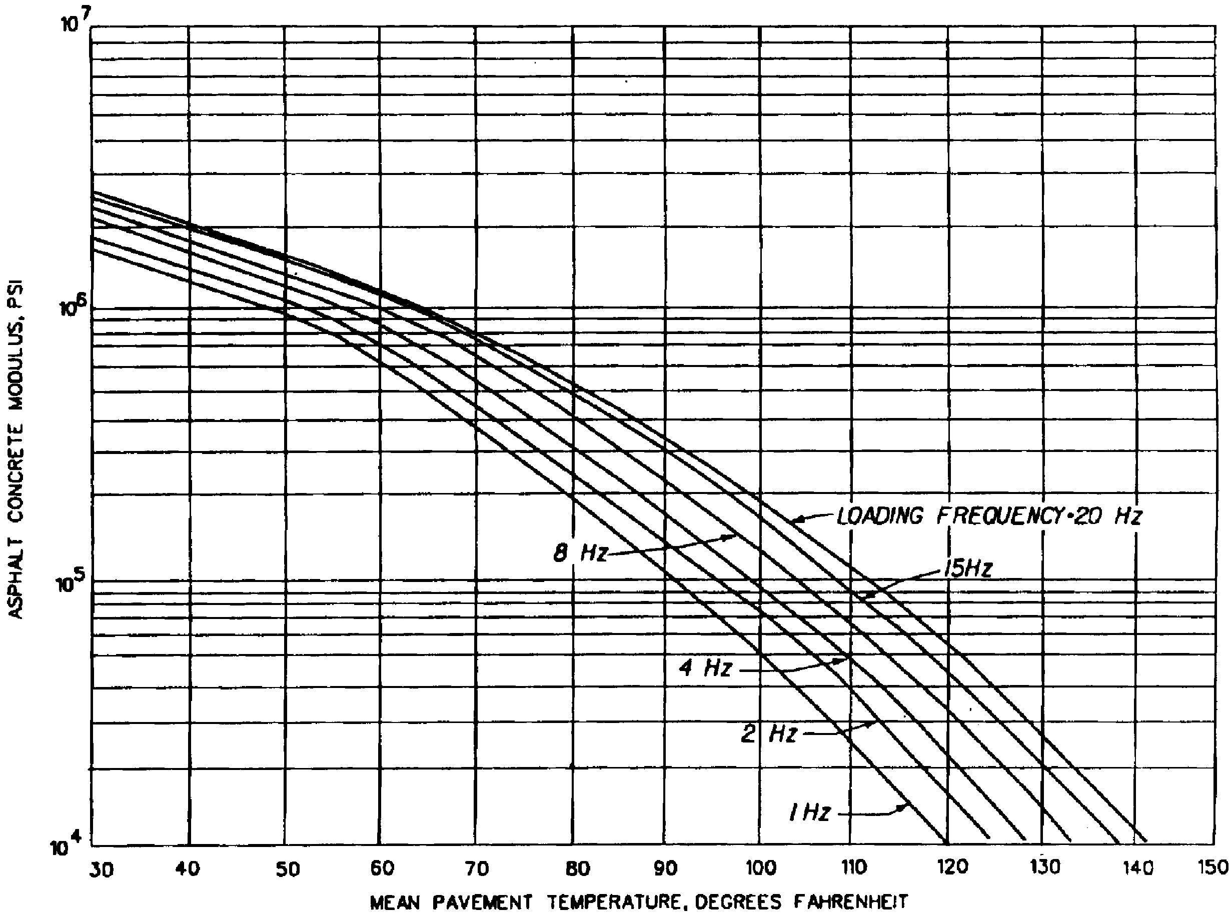

Figure 4-2. Prediction of Asphalt Concrete Modulus for Bituminous Layers.

established. If temperature data indicate greater extremes than 40 and 100 degrees F., tests should be conducted at these extreme ranges, if possible. The modulus value to be used for each strain computation would be the value applicable for the specific pavement temperature determined from the climatic data.

(b) An indirect method of obtaining an estimated modulus value for bituminous concrete is presented in detail in TM 5-825-2-l/AFM 88-6, Chap. 2, Section A. Use of this method requires that the ring-and-ball softening point and the penetration of the bitumen as well as the volume concentration of the aggregate and percent air voids of the compacted mixture be determined. The modulus of bituminous concrete may also be estimated from the design pavement temperature using figure 4-2.

(2) *Portland cement concrete (PCC).* The modulus of elasticity and flexural strength of PCC will be determined from static flexural beam tests in accordance with ASTM C 78. When test results are not available, a modulus value of 4,000,000 psi may be assumed for the concrete. Proportioning of the concrete mix and control of the concrete for pavement construction will be in accordance with TM 5-822-7/AFM 88-6, Chap. 8.

(3) *Unbound granular base and subbase course materials.* The terms "unbound granular base course material" and "unbound granular subbase course material" as used herein refer to materials meeting grading requirements and other requirements for base and subbase for roads and streets, respectively. These materials are characterized by use of a chart in which the modulus is a function of the underlying layer and the layer thickness. The chart and the procedure for use of the chart are given in appendix B. The modulus values of unbound granular bases may also be determined from cyclic triaxial tests on prepared samples. The recommended test procedure is outlined in TM 5-825-3-1/AFM 88-6, Chap. 3, Section A. The base course under a rigid pavement can be unbound granular or a chemically stabilized material. Design using stabilized materials is described in the next section.

(4) *Stabilized material.* The term "stabilized material" as used herein refers to soil treated with such agents as bitumen, portland cement, slaked or hydrated lime, and flyash or a combination of such agents to obtain a substantial increase in the strength of the material over the material's untreated natural strength.

Stabilization with portland cement, lime, flyash, or other agent that causes a chemical cementation to occur shall be referred to as chemical stabilization. Chemically treated soils having unconfined compressive strengths greater than the minimum strength are considered to be stabilized materials and should be tested in accordance with the methods specified for stabilized materials. Chemically treated soils having unconfined compressive strengths less than the minimum strength are considered to be modified soils. Most likely this will result in using the maximum allowable subgrade modulus. Bituminous-stabilized materials should be characterized in the same manner as bituminous concrete. Stabilized materials other than bituminous stabilized should be characterized using cracked section criteria, which is explained later in conjunction with figure 4-3.

(a) Stabilized materials for the base and subbase must meet the strength and durability requirement of TM 5-822-14/AFJMAN 32-1018. The basic strength requirements are presented in table 4-1.

Table 4-1. Minimum Unconfined Compressive Strengths for Cement, Lime, and Combined Lime-Cement Flyash Stabilized Soils.

	Minimum Unconfined Compressive Strength,* pounds per square inch	
Stabilized Soil Layer	Concrete Pavement	Flexible Pavement
Base Course	500	750
Subbase course, select material, or subgrade	200	250

*Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime or lime-cement-flyash stabilization.

(b) Lime-stabilized materials will continue to gain strength with time; therefore, if sufficient evidence is available that indicates a lime-stabilized material will acquire adequate strength prior to traffic, then the 28-day strength requirement may be waived.

(c) For concrete pavements having a stabilized base or subbase, the determination of elastic modulus values becomes more complicated than for the pavement with unbound granular base. Two cases in particular should be considered. In the first case, where the stabilized layer is considered to be continuous with cracking due only to curing and temperature, the elastic modulus values may be determined from flexural beam tests. In the second case, the stabilized layer is considered cracked because of load. Once the cracks have developed extensively in the stabilized base, the layer would behave as a granular material but with a higher modulus value. The cracked stabilized base course is represented by a reduced resilient modulus value, which is determined from the relationship between resilient modulus and unconfined compressive strength shown in figure 4-3. This relationship may be used for concrete pavement design for roads and streets.

(d) The general, material, and compaction requirements of base courses under a pavement are described in TM 5-822-5/AFM 88-7, Chap. 3.

(5) *Subgrade soils.* The term "subgrade" as used herein refers to the natural, processed, or fill soil foundation not meeting the requirements for a base or subbase on which a pavement structure is placed. The modulus of the subgrade is determined through the use of the repetitive triaxial test. The procedure is described in TM 5-825-2-1/AFM 88-6, Chap. 2, Section A. For most subgrade soils, the modulus is greatly affected by changes in moisture content and state of stress. As a result of normal moisture migration, water table fluctuation, and other factors, the moisture content of the subgrade soil can increase and approach saturation with only a slight change in density. Since the strength and stiffness of fine-grained materials are particularly affected by such an increase in moisture content, these soils should be tested in the near-saturation state.

(a) Procedures for specimen preparation, testing, and interpretation of test results for cohesive and granular subgrades are presented in TM 5-825-2-1/AFM 88-6, Chap. 2, Section A. For the layered elastic theory of flexible pavement design, the maximum allowable modulus for a subgrade soil should be restricted to 30,000 pounds per square inch (psi).

(b) In areas where the subgrade is to be subjected to freeze-thaw cycles, the subgrade modulus must be determined during the thaw-weakened state. Testing soils subject to freeze-thaw requires specialized test apparatus and procedures. The Cold Regions Research and Engineering Laboratories (CRREL) can assist in characterizing subgrade soils subjected to freeze-thaw.

(c) For some design situations, estimating the resilient modulus of the subgrade (MR) based on available information may be necessary when conducting the repetitive load triaxial tests. An estimate of the resilient modulus can be made from the relationship of MR = 1500 • CBR, where CBR is the California Bearing Ratio. This relationship provides a method for checking the reasonableness of the laboratory results.

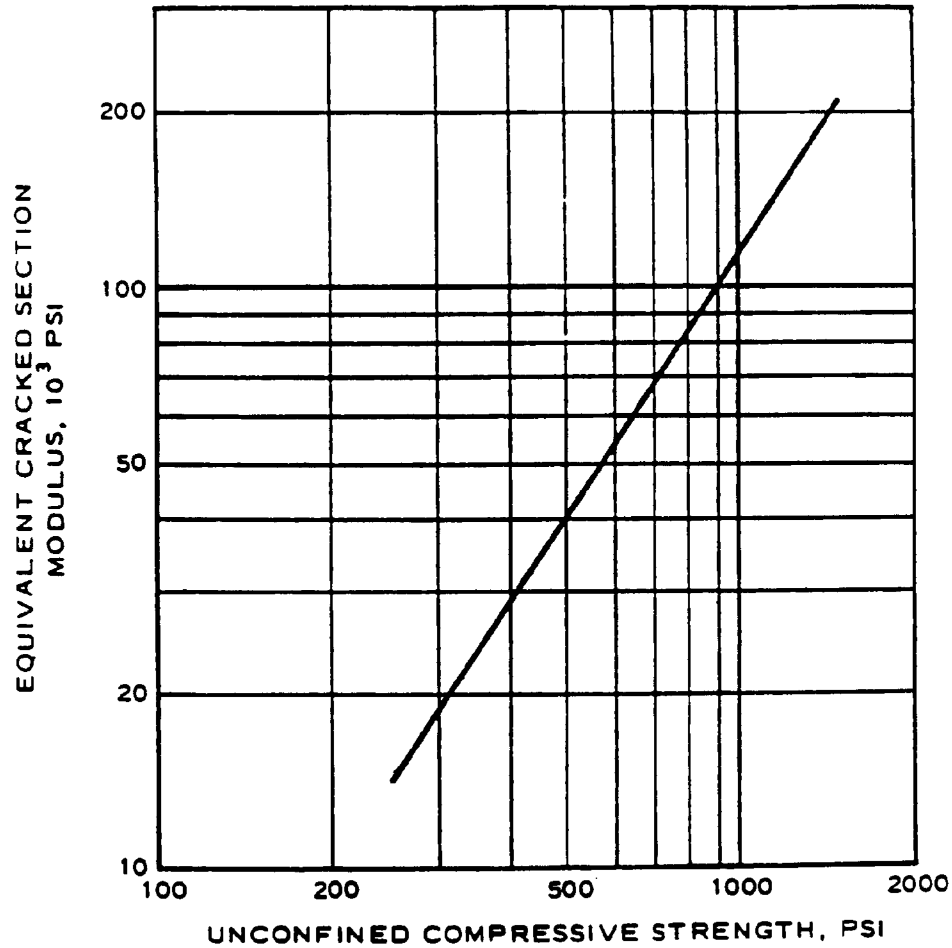

Figure 4-3. Relationship Between Equivalent Cracked Section Modulus and Unconfined Compressive Strength.

The relationship shown in figure 4-4 may be used to estimate the elastic modulus from the modulus of soil reaction k. It is to be noted that the relationship shown in figure 4-4 is established based on limited data. The modulus of soil reaction k can be determined using the plate-bearing test in the field or from table 4-2 when field test results are not available.

*Table 4-2. Modulus of Soil Reaction.**

	Moisture content percentage							
Type of material	1 to 4	5 to 8	9 to 12	13 to 16	17 to 20	21 to 24	25 to 28	Over 28
Silts and clays, LL greater than 50 (OH, CH, MH)	—	175	150	125	100	75	50	25
Silts and clays, LL less than 50 (OL, CL, ML)	—	200	175	150	125	100	75	50
Silty and clayey sands (SM and SC)	300	250	225	200	150	—	—	—
Sand and gravelly sands (SW and SP)	350	300	250	—	—	—	—	—
Silty and clayey gravels (GM and GC)	400	350	300	250	—	—	—	—
Gravel and sandy gravels (GW and GP)	500	450	—	—	—	—	—	—

Notes:

1. Values of k shown are typical for materials having dry densities equal to 90 to 95 percent of the maximum. For materials having dry densities less than 90 percent of the maximum, except that a k of 25 pci will be the minimum used for design.
2. Values shown may be increased slightly if density is greater than 95 percent of the maximum except that a k of 500 pci will be the maximum used for design.
3. Frost-melting-period k values are given in TM 5-822-5/AFM 88-7, Chap. 3.

*Typical values k in pci for rigid pavement design.

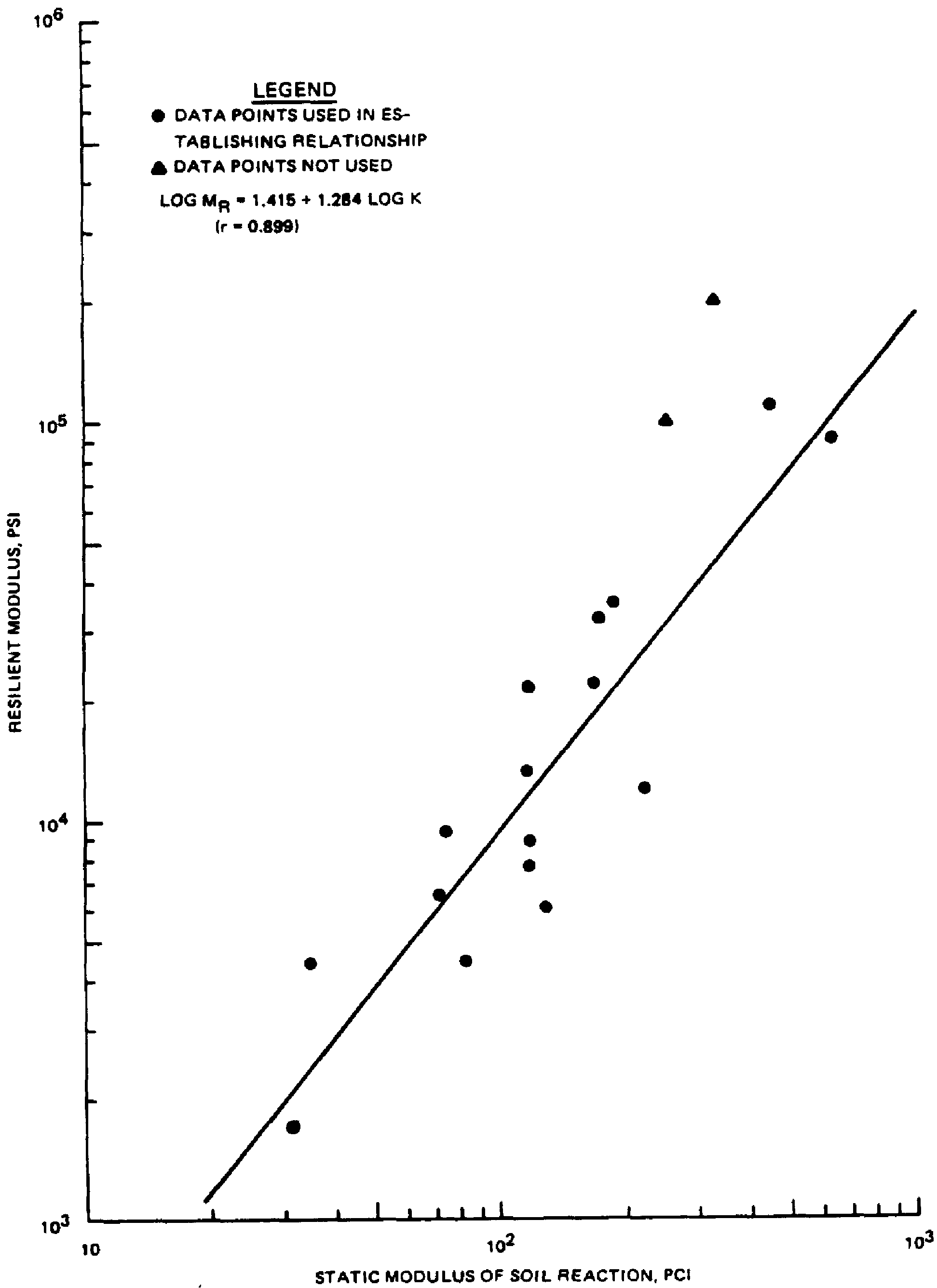

Figure 4-4. Correlcation Between Resilient Modulus of Elasticity and Static Modulus of Soil Reaction.

b. Poisson's ratio. Poisson's ratio is difficult to determine and has relatively minor influence on the design compared to other parameters. Therefore, commonly recognized values of Poisson's ratio are used. These values are as follows:

Pavement Material	Poisson's Ratio v
Portland cement concrete	0.15 ~ 0.20
Bituminous concrete	0.5 for E < 500,000 psi 0.3 for E > 500,000 psi
Unbound granular base or subbase course	0.3 ~ 0.35
Chemically stabilized base or subbase course	0.2
Subgrade	
Cohesive subgrade	0.4
Cohesionless subgrade	0.3

4-3. Nondestructive Testing Procedure.

When computer programs are used to compute the stresses and strains in a pavement, the input needed is the elastic moduli of the pavement layers. The modulus values may be determined using the nondestructive testing (NDT) procedure presented in TM 5-826-5/AFP 88-24, Chap. 5. The NDT procedure used in this manual is the falling weight deflectometer (FWD). With the FWD the deflection basins of the pavement can be measured. Based on the measured deflection basins, the elastic modulus of the pavement material in each layer can be backcalculated by a computer program WESDEF available at US Army Engineer Waterways Experiment Station (WES) (TM 5-826-5/AFP 88-24, Chap. 5).